TOPICS IN TRAINING

Learning and Retaining Simulated Arthroscopic Meniscal Repair Skills

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Background: Previous studies of task-specific skills have suggested that a loss of technical performance occurs if the skill is not practiced for a six-month period. The aims of this study were to objectively demonstrate the learning curve for a complex arthroscopic task (meniscal repair) by means of motion analysis and to determine the impact of task repetition on the retention of this skill.

Methods: Nineteen orthopaedic residents with experience in routine knee arthroscopy but not in arthroscopic meniscal repair were recruited into a randomized study. During the initial learning phase, all subjects performed twelve meniscal repairs on a knee simulator over a three-week period. A validated motion analysis tracking system was used to objectively record the performance and learning of each subject; the outcomes were the time taken, distance traveled, and number of hand movements. The subjects were then randomized into three groups. Group A performed one meniscal repair each month, Group B performed one meniscal repair at three months, and Group C performed no repairs during this interim phase. All three groups then returned at the six-month point for the final assessment phase, during which they carried out an additional twelve meniscal repairs over three weeks.

Results: All subjects demonstrated a clear learning curve during the initial learning phase, with significant objective improvement in all motion analysis parameters over the initial twelve episodes ($p < 0.0001$). Although some residents had reached a learning plateau by twelve episodes, others continued to make further improvements for up to another nine episodes. Importantly, Group C did not display any loss of skill between the initial learning phase and final evaluation phase despite a six-month break in task repetition ($p > 0.05$).

Conclusions: In contrast to previous studies, residents did not lose any skill over a six-month interruption in task performance, and other residents took longer to produce a more consistent performance.

Clinical Relevance: These findings suggest the presence of task-specific and surgical group-specific factors that affect the retention of arthroscopic skills. The use of generic guidelines on minimum task frequency for learning and maintaining optimal performance of arthroscopic tasks by surgeons may not be appropriate.

There has been a recent focus on improving methods of teaching and assessing the education of surgical residents[1]. In many countries, there is now a compulsory requirement for trained surgeons to demonstrate their technical skill and operative outcomes as part of recertification processes[2,3]. Previous studies of specific procedures have shown that improved outcomes

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are achieved by surgeons who perform a high volume of that procedure[4,5].

In many countries, working time directives have led to a reduction in training time and concerns about surgical training opportunities[6]. This has encouraged the exploration of alternative methods of developing surgical skills outside the operating room. This is particularly pertinent for less commonly performed but intricate surgical procedures. The role of simulation in medical education is well established, with increasing use in both general and orthopaedic residency training[1,7-12].

Recognition of the chondroprotective effect of the menisci has increased in recent years[13-15], and greater efforts to retain meniscal tissue have led to more frequent meniscal repair. Recent device developments have facilitated an all-inside meniscal repair technique, which remains a technically demanding procedure[16,17]. Since orthopaedic surgeons perform this procedure

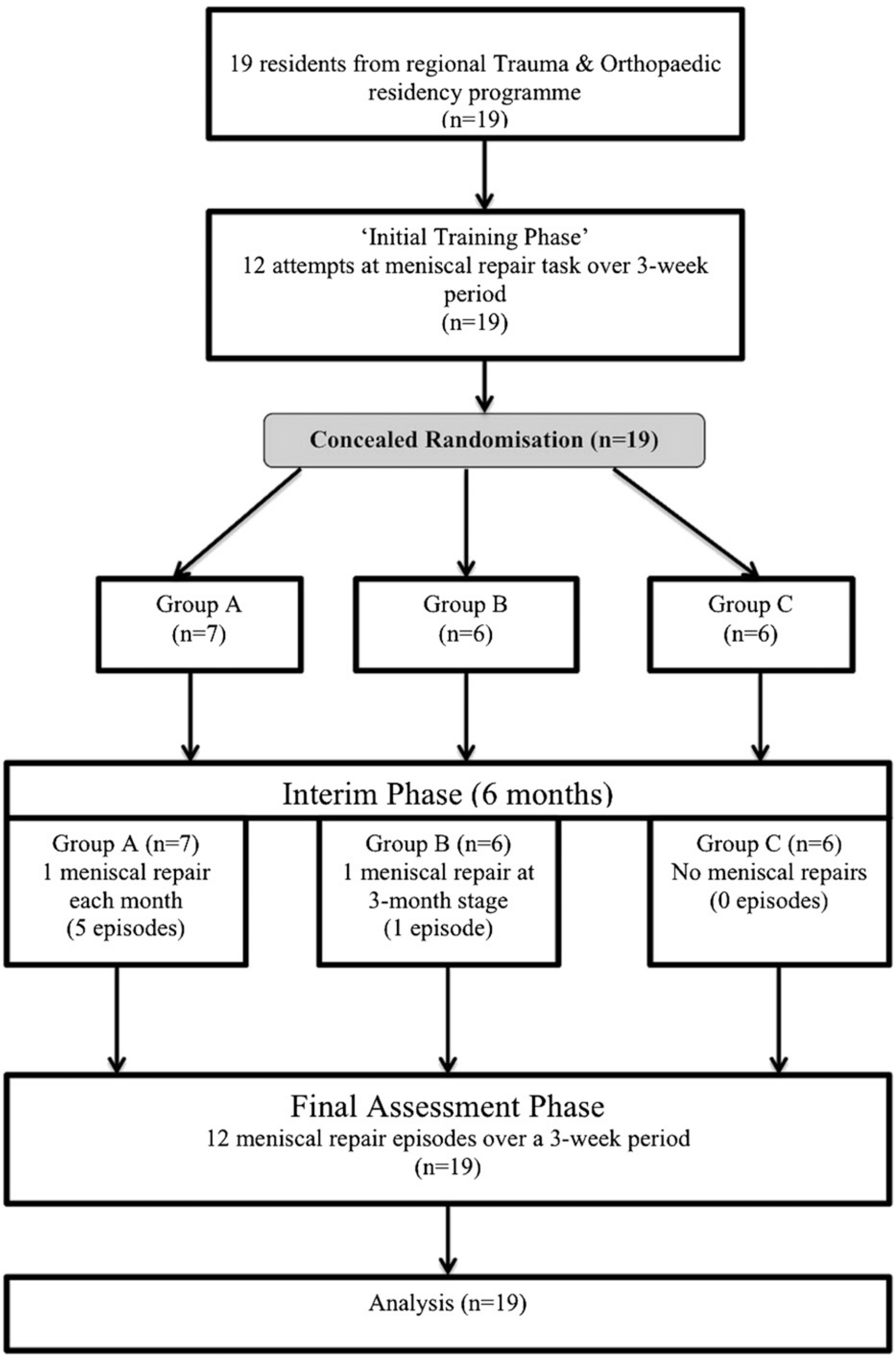

Fig. 1
Flow of subjects through the randomized trial.

infrequently unless they have a subspecialty interest in soft-tissue knee surgery, questions arise regarding how best to train surgeons to perform this procedure and how frequently these skills should be practiced to allow optimum retention of surgical skill.

A recent study has shown that psychomotor skills learned in a simulated environment appear to deteriorate significantly after four months without repetition[18]. Motion analysis can objectively demonstrate the learning curve for an arthroscopic procedure, and one orthopaedic study indicated loss of a new arthroscopic skill if it was not practiced for a six-month period[19].

The aims of the present study were to investigate the learning curve of orthopaedic residents who were being taught arthroscopic meniscal repair on a knee simulator and to determine the effect of frequency of repetition on skill retention.

Materials and Methods

Subjects

Nineteen orthopaedic residents from a regional training program were recruited. Each subject was required to have performed at least twenty diagnostic knee arthroscopies as the primary surgeon (as indicated by the subject's surgical log books) and to have demonstrated the ability to competently perform a diagnostic knee arthroscopy under supervision (as assessed with use of a nationally

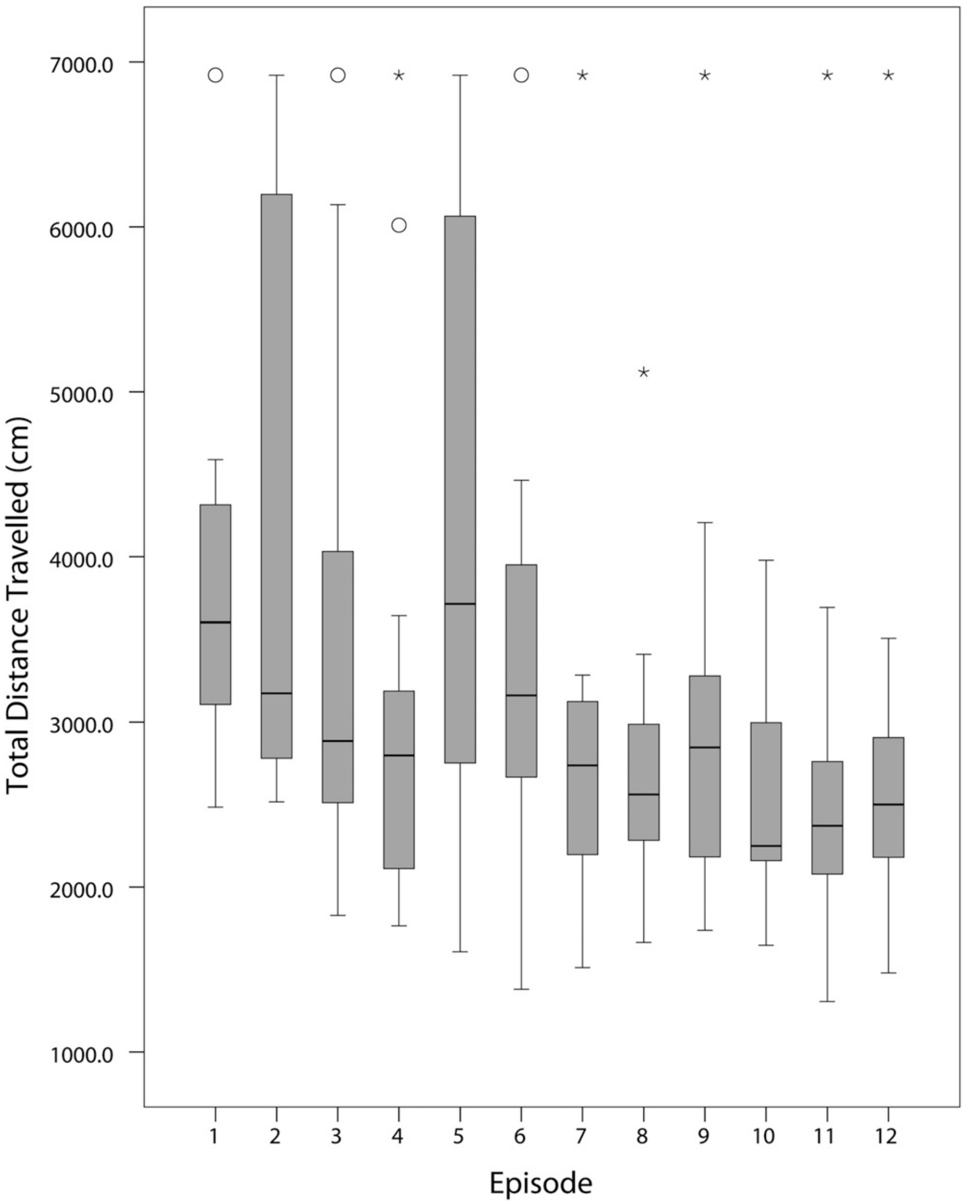

Fig. 2

Motion analysis assessment of subjects in the initial training phase as measured by the total path length. In this and the following figures, the 25th and 75th percentiles are depicted as a box, the median is depicted as a line within the box, other data points within 1.5 times the interquartile range are depicted as whiskers, and outliers within and not within three times the interquartile range are depicted as circles and asterisks, respectively.

approved competency checklist[20]). The designated minimum of twenty diagnostic knee arthroscopies was based on a previous study that demonstrated stabilization of learning curves after completion of eighteen arthroscopies[12]. This experience provided the subject with the necessary basic psychomotor skills to progress to learning a more complex arthroscopic task. Exclusion criteria included previous surgical experience in meniscal repair. Institutional review board approval was granted for this simulation study, and the residents gave informed consent to participate.

Simulator Training

A knee simulator model (Sawbones Europe, Malmö, Sweden) was set up in a designated skills laboratory. A standardized longitudinal peripheral tear was made in all lateral meniscal inserts of the model. Optimal entry points for insertion of the meniscal suture anchors were marked with an "x." The position of the "x" was determined by the first author, who had performed over 100 arthroscopic meniscal repairs with use of the all-inside technique. A standard 30° arthroscope, arthroscopic camera, and display system (Smith & Nephew Endoscopy, Huntingdon, United Kingdom) was used in all tests. Each resident was shown an instructional video outlining the instruments, the technique of all-inside meniscal repair, and the specific task to be performed, prior to the first attempt to perform the procedure. Written sequential instructions were displayed next to the knee simulator model for all of the subsequent repetitions, but no further training was given. A standard horizontal mattress suture configuration was employed. The end point of the task was completion of the placement of a single meniscal suture across the meniscal tear. Each subject then performed a total of twelve meniscal repairs (three sets of four repairs) over a three-week period (the initial training phase).

At the end of the initial training phase, each subject was randomized into one of three groups with use of sealed opaque envelopes and entered a six-month interim phase. Group A (n = 7) performed the meniscal repair task once each month for the next five months. Group B (n = 6) performed the task once, three months after the end of the initial training phase. Group C (n = 6) did not perform the task during the six-month period.

During the final assessment phase, which began six months after the end of the initial training phase, each resident attempted the task an additional twelve times over a three-week period (four episodes per session). Since the subjects continued their orthopaedic residency program during the study, they were asked at each visit to report any meniscal repair episodes that they had been involved in as part of their ongoing clinical training. They were not shown the instructional video again, and they were given no instruction or reminders regarding how to perform the task except for the written sequential instructions. Figure 1 illustrates the flow of residents through the trial.

Motion Analysis

A three-dimensional electromagnetic motion tracking system (PATRIOT; Polhemus, Colchester, Vermont) was used to objectively measure surgical performance. This tracking technology has been used previously and has been validated as an accurate and reproducible assessment tool in laparoscopic surgery[10,11,21,22], open general surgery[23], and more recently arthroscopic surgery[19,24]. The system consists of two small sensors that were placed in fixed positions on the dorsum of the subject's hands and an emitter that was attached to the simulator. The output consists of the three-dimensional position (x, y, and z coordinates) of each sensor relative to the emitter as a function of time. Processing of this information after the trial provides three variables: the time

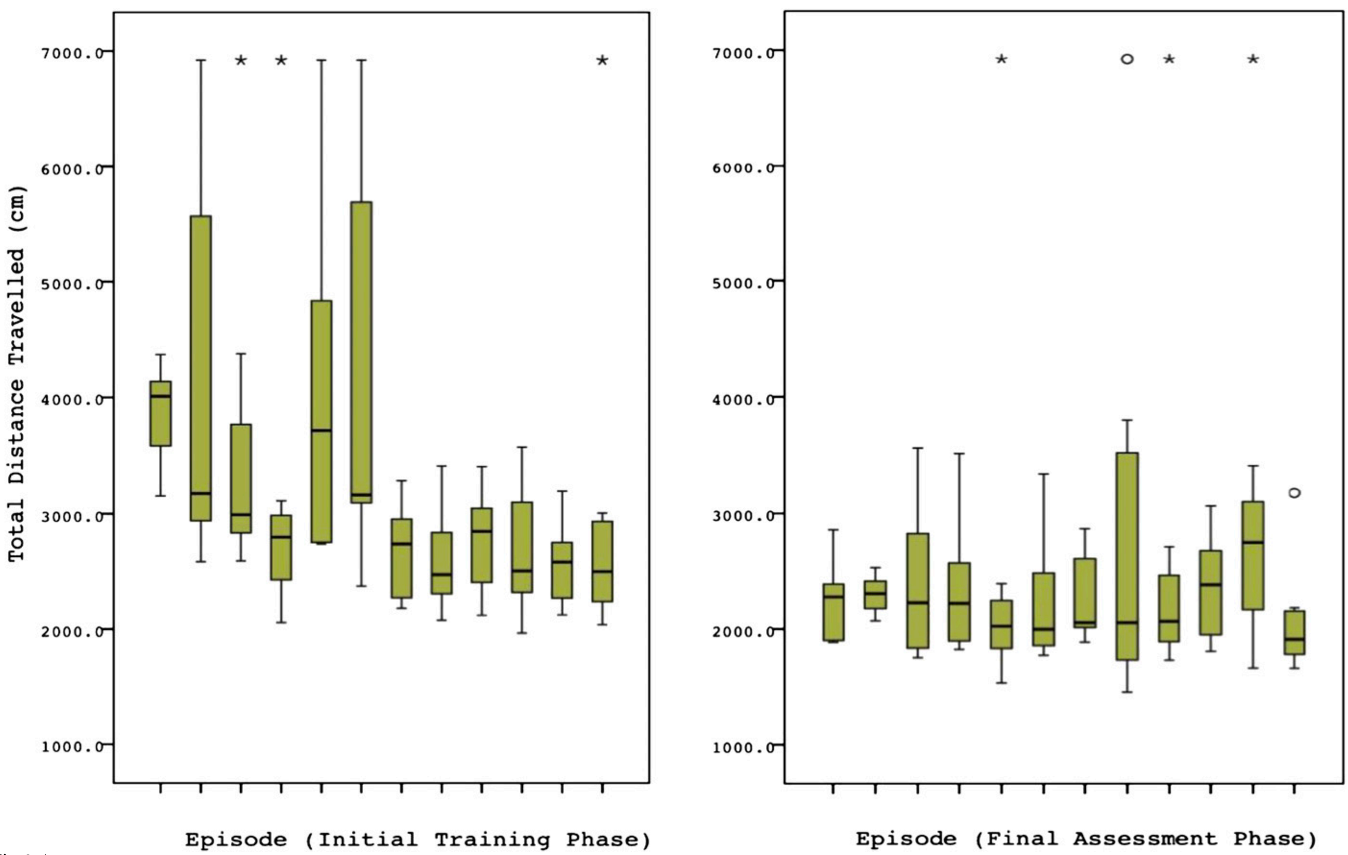

Fig. 3-A
Task performance of Group A (monthly repetition during the interim period) in the initial training phase and in the final assessment phase as measured by the total distance traveled.

taken, number of hand movements, and distance traveled by the surgeon's hands. A standardized simulator environment was maintained at all times. The calibration procedures demonstrated a consistent simulator environment that provided reliable and repeatable outputs. Validation studies have found this assessment tool and its outcome parameters to be capable of differentiating between surgeons of differing abilities; those with greater technical skill perform procedures in less time, requiring fewer hand movements with a shorter total path length[24].

Task Failure

Two independent assessors (one attending surgeon and one senior resident) performed an assessment of each meniscal repair. The adequacy of the repair was evaluated by direct observation of the meniscal entry points. Inappropriate suture position or a gap of >3 mm between the edges of the meniscal tear resulted in a designation of a failed repair.

Statistical Analysis

Statistical analysis of the motion analysis variables (total distance traveled, number of hand movements, and time taken) was performed with use of SPSS software (version 18; SPSS, Chicago, Illinois). The Wilcoxon signed-rank test was used both to compare performance among individuals and to compare performance between the initial assessment phase and the final assessment phase in order to demonstrate skill retention. The Fisher exact test was used to compare the frequency of task failure. Task failures were accounted for in the motion analyses with use of a standard statistical method in which a "failure score" was assigned to each failure episode by adding one standard deviation to the worst successful score (for each motion analysis variable). A p value of <0.05 was considered significant.

Source of Funding

The study was funded by the British National Institute for Health Research (NIHR).

Results

Cohort Demographics

The randomized groups were similar in terms of level of training and previous knee arthroscopy experience. None of the residents had performed real-life meniscal repair either prior to the study or during the study period.

Initial Training Phase

A learning curve was demonstrated by the residents over the course of the initial training phase, with clear improvement in all three of the motion analysis variables. The median time taken for the task improved from 378 seconds (interquartile range [IQR], 213 seconds; standard error [SE], 30 seconds) to 200 seconds (IQR, eighty-two seconds; SE, 24 seconds), the median number of hand movements improved from 230 (IQR, 178; SE, twenty-one) to 160 (IQR, seventy-two; SE, sixteen), and the median distance traveled improved from 3175 cm (IQR, 1690 cm; SE, 208 cm) to 2372 cm (IQR, 789 cm; SE, 169 cm). These improvements were significant for all three motion analysis parameters ($p < 0.0001$). Figure 2 demonstrates

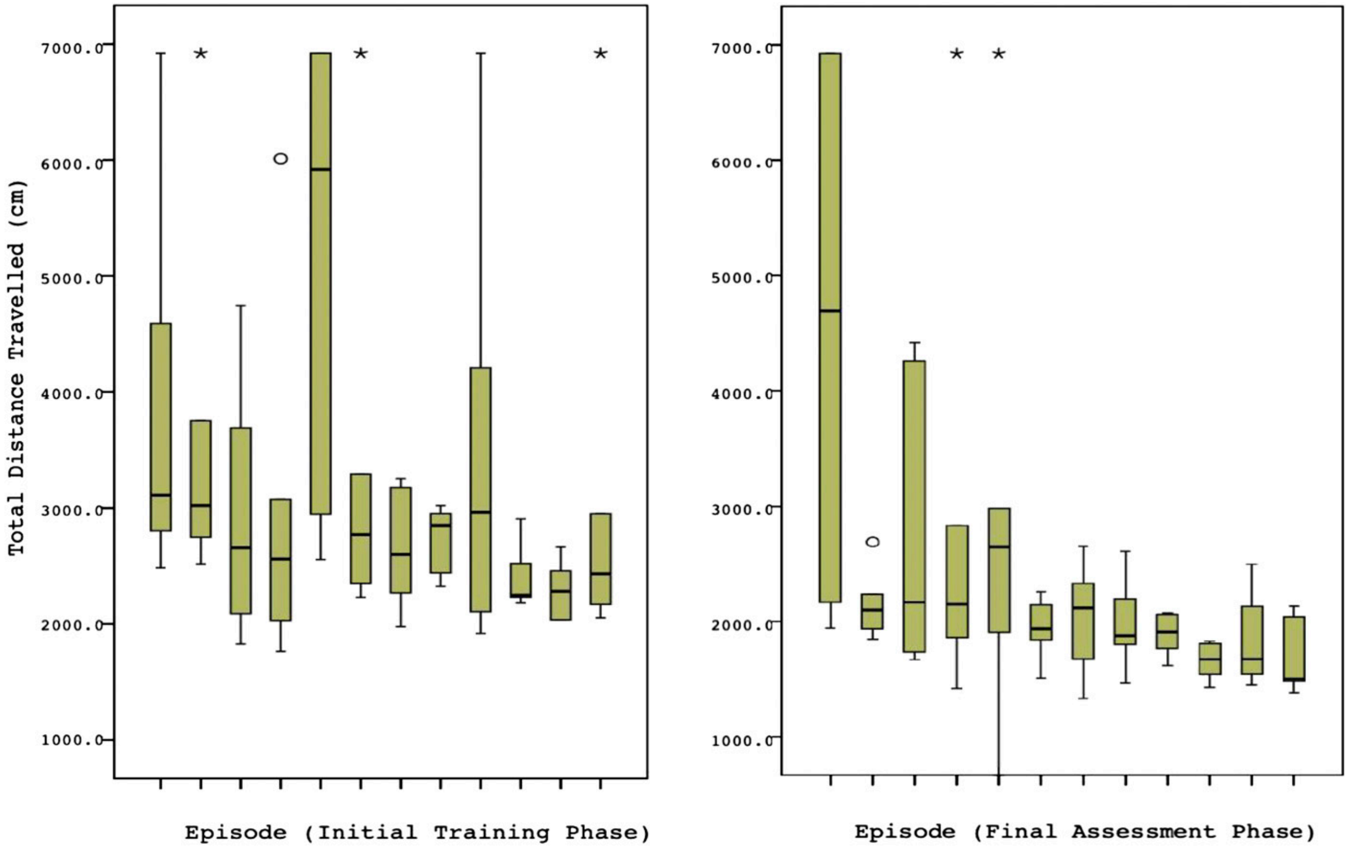

Fig. 3-B

Task performance of Group B (one repetition during the interim period) in the initial training phase and in the final assessment phase as measured by the total distance traveled.

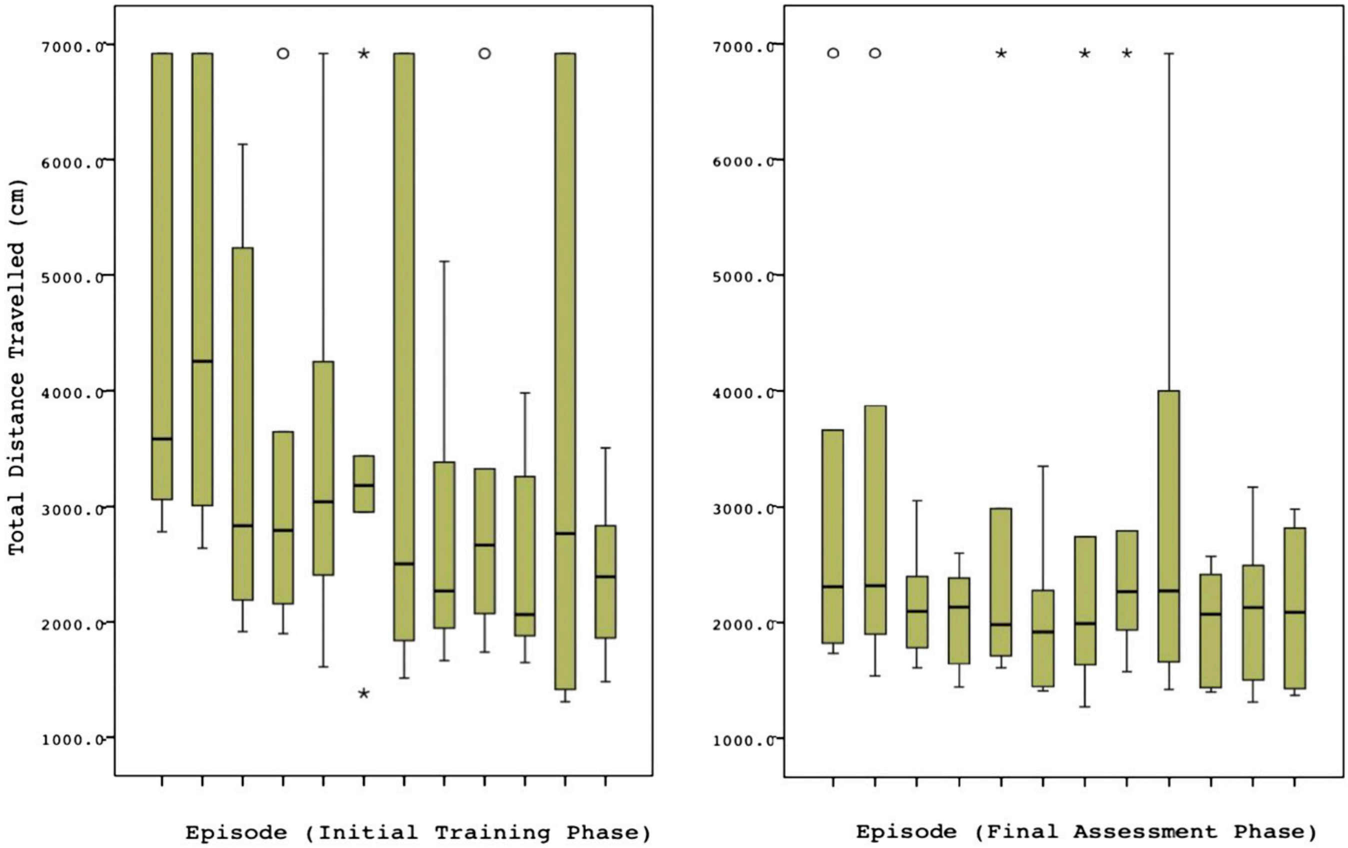

Fig. 3-C

Task performance of Group C (no repetitions during the interim period) in the initial training phase and in the final assessment phase as measured by the total distance traveled.

the learning curve for the entire study cohort during the initial training phase as measured by the total distance traveled in the motion analysis.

Interim and Final Assessment Phases

All residents reached a plateau in their performance by twenty-one episodes. Although the majority of the learning took place during the first twelve episodes, residents in Group A continued to show small improvements for up to a further six episodes, Group B displayed learning for a further nine episodes, and Group C did not show any further improvement after twelve episodes. Despite not performing any task repetitions during the interim period, Group C showed no deterioration in performance after a six-month break, as measured by all motion analysis parameters ($p > 0.05$). Figures 3-A, 3-B, and 3-C demonstrate the task performance in the initial training phase compared with the final assessment phase for each group, as measured by the total distance traveled.

Task Failures

Overall, the number of episodes of task failures decreased significantly between the initial training phase (twenty-eight) and the final assessment phase (fifteen) ($p = 0.027$, Fisher exact test).

Discussion

The present study objectively demonstrated a learning curve for meniscal repair performed by orthopaedic residents on a knee simulator. Although some residents demonstrated learning curves that plateaued within twelve episodes as reported previously, other residents continued to make small improvements up to twenty-one episodes before appearing to reach a level of consistent performance of this particular task. Also in contrast to previous studies that demonstrated skill loss over a six-month period without repetition[19,25], residents in our study who did not perform this task for six months were able to retain their level of skill and performance.

To help explain these new findings, it is worth looking at the work of Rasmussen, who studied the manner in which complex tasks are organized and processed by individuals. Three domains of behavior were identified[26]. This classification of “skill-based,” “rule-based,” and “knowledge-based” behaviors has been adapted for understanding the processes involved in learning surgical procedures[27,28]. Skill-based behaviors are a group of specific motor movements that are required during a procedure and are regulated by continuous feedback. Rule-based behaviors include particular operative steps that are based on certain principles. Knowledge-based behaviors are used in tackling unexpected situations or complications for which there are no rules available; they are dependent on the individual's fundamental knowledge and experience of the task. According to Rasmussen's model, each procedure or task requires differing degrees of skill-based, rule-based, and knowledge-based behaviors. This suggests that the learning and retention of technical skills is task-specific. It has been suggested that individuals are more receptive to retaining a skill if they are primed to learn it and can see long-term benefits in retaining it[29]. The learning process for surgical residents may differ from that of other groups, particularly during development of a skill that is directly applicable to them or their future practices. This is further highlighted by studies that have demonstrated better learning by medical students compared with residents on a surgical simulator, with greater retention of skill at six months. The authors of that study commented that the difference may be related to the eagerness of the students and a more intense initial period of learning[30].

The results of the present study imply that both task-specific and surgical group-specific factors impact learning and retention of skill, with some groups showing less performance variability and learning within twelve episodes whereas others demonstrated more variability in performance and took up to twenty-one episodes. There is evidence from some areas of orthopaedic practice that the frequency of performing a surgical procedure affects outcome, with low-volume surgeons achieving poorer results[4,5,31,32]. Although it may seem likely that the volume of cases plays a role in surgical outcome and performance, the present study pertaining to arthroscopic training implies that care needs to be taken not to apply generic advice such as minimum numbers of repetitions, as task-specific and surgeon-specific factors play an important role.

It is therefore important to monitor learning and performance of arthroscopy and not just rely on minimum numbers of repetitions to guarantee skill acquisition. Although motion analysis has been able to objectively demonstrate learning and improvement for this and other arthroscopic tasks, it cannot be used in the operating room, and it is therefore important to explore and develop valid "user-friendly" objective skill assessment methods that can be used in the operating room.

Despite the use of randomization, this study has some limitations. Insufficient power is a possibility in studies of this type, but nineteen subjects performing at least twenty-four task episodes exceeds the numbers in many similar studies. Recruitment was restricted to residents within the regional orthopaedic residency program who were at the appropriate stage in training, and it would have thus been logistically difficult to study a larger group. As in clinical practice, the "all-inside" meniscal repair device sometimes fails to deploy optimally despite seemingly appropriate use, and instances of device failure may have contributed to task performance in this study. However, twenty-eight (12%) of 228 task episodes in the initial training phase were failures. This improved to fifteen (7%) of 228 task episodes in the final assessment phase, suggesting that only a small percentage of task failures might be attributed to failure of the device.

In conclusion, this study clearly demonstrated a learning curve for arthroscopic meniscal repair using a surgical simulator, and it again confirmed the value of repetition in learning and retaining simulated arthroscopic meniscal repair skill. In contrast with some previous studies, the residents in the present study all maintained their skill even with a six-month lack of practice, suggesting that the learning rate of arthroscopic procedures is affected by the task and the surgical group. Caution should therefore be used in applying generic guidelines regarding the number of cases thought to be necessary to acquire proficiency and maintain surgical performance. ■

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